LA-ICP-MS analysis of Clovis period projectile points from the Gault Site

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A R T I C L E   I N F O

A B S T R A C T

A key tenet of Clovis period hunter–gatherer mobility is the utilization of large ranges based on the appearance of exotic raw materials, particularly chert, in Clovis assemblages. The identification of the sources of chert in Clovis period assemblages is problematic as it has relied on macroscopic properties.

Macroscopic characteristics of chert can be highly variable in a single outcrop, occur across very large areas, and have correlates in unrelated and far removed contexts. An instrumental geochemical approach was utilized that potentially offers advances in the capacity to link chert artifacts to their sources. Trace element data was recovered from 33 Clovis period projectile points from the Gault Site (41BL323) using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS). This data was compared to trace element data recovered from 224 primary geologic samples of chert from multiple primary sources across the Edwards Plateau in Texas. The Clovis points were compared to the geologic sources using canonical discriminant analysis to establish group membership at three spatial scales: macro-regional (greater than 500 km), regional (between 30 and 500 km), and local (between 1 and 30 km). It was found at the macro-regional scale that 21 of the 33 Clovis points were to be geochemically similar to Edwards Plateau sources. At the regional scale, 15 of the 21 identified Edwards Plateau Clovis points could be attributed to a particular source. Lastly, only two Clovis points could be identified to particular sources at the local scale.

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1. Introduction

Tracing the long distance movement of Clovis chert artifacts across the landscape has long been a mainstay for inferring Clovis land use (Anderson, 1996; Meltzer, 1984; Bamforth, 2009; Estes, 2009; Wittoft, 1952; Goodyear, 1979; Bamforth and Becker, 2000; Hofman et al., 1991; Meltzer, 1989; Holen, 2001; Speth et al., 2013; Anderson and Gillam, 2000; Gingerich, 2013a; Kelly and Todd, 1988). The inference of large ranges based on the appearance of exotic raw materials, particularly chert, in Clovis assemblages, along with predominantly brief-interval Clovis sites, shaped theories of Clovis period hunter–gatherer mobility (Meltzer, 1984; Hofman et al., 1991; Holen, 2001; Kelly and Todd, 1988; Meltzer, 2002; Ellis, 2011; Boldurian and Cotter, 1999; Bamforth, 2003; Frison, 1991; Cable, 1996; Wyckoff, 2005; Goodyear, 1989; Kilby, 2008; Gingerich, 2013b; Eren and Andrews, 2013; Jennings, 2013). The identification of the sources of chert used in Clovis assemblages have primarily relied on macroscopic properties and influenced how archaeologists interpret the core features and concepts of Clovis period mobility. Macroscopic characteristics of chert can be highly variable in a single outcrop, occur across a very large area, and have similar correlates in completely unrelated and far removed contexts (Frederick et al., 1994; Luedtke and Meyers, 1992; Banks, 1990; Crandell, 2014). This is none more evident than the identification of Edwards chert in Paleoindian contexts far from the source area (Hofman et al., 1991; Boldurian and Cotter, 1999); but identification of a gray, cryptocrystalline silicate does not necessarily indicate that an artifact is derived from an Edwards Plateau source. There are numerous other sources of variable gray, cryptocrystalline silicates in other regions across North America. For example, Reed Springs chert in Missouri, Arkansas, and Oklahoma, Dongala chert in Illinois, Fort Payne chert in Tennessee and Kentucky, Upper Mercer chert in Ohio, Wyandotte chert in Indiana and Kentucky, and many others sources can appear identical to sources found on the Edwards Plateau (Banks, 1990; Ray, 2007), especially if somewhat patinated. Macroscopically similar chert also occurs at the northern and southern boundaries of the Edwards Plateau; potentially meaning a difference of 350 km (see

Fig. 1). This is significant when considering that smaller distances (some estimate 30 km) are generally accepted as the difference between a local versus non-local toolstone for most hunter—gatherer populations (Holen, 2001; Meltzer, 2006; Munson and Munson, 1984; Tankersley, 1989; Tankersley and Morrow, 1993). Geochemical sourcing of Edwards Plateau chert represents an advance over macroscopic identification alone and can enhance the precision and accuracy of source assignments as seen in other chert sourcing studies (Ekshtain et al., 2014, Evans et al., 2007, Evans et al., 2010, Milne et al., 2009, Milne et al., 2011).

Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS) is an effective method for determining geochemical concentrations found in artifacts with minimal damage and rapid spot analysis (rather than bulk analysis) (Pitblado et al., 2013; Pettitt et al., 2012; Speakman and Neff, 2005a). This study evaluates the trace element geochemistry of Clovis period projectile points from the Gault Site (41BL323) in Central Texas with LA-ICP-MS (see Table 1). It will compare this data to the trace element geochemistry of geologic chert samples from multiple areas of the Edwards Plateau in Texas and from geologic chert samples from one area of the Knife River in North Dakota. This study compares Clovis period projectile points with these geologic samples at the three spatial scales mentioned above. Canonical discriminant analysis is used to establish group membership for each of the artifacts. Detailed anthropological implications of this study will be presented in the context of understanding Clovis period hunter—gatherer mobility in future publications.

2. Background

This study compares the geochemistry of Clovis period artifacts to that of several geologic areas across several areas of the Edwards Plateau and one area in North Dakota, see Speer (2014). Knife River

Table 1
Artifact samples tested.

| Artifact	Artifact type	Reference number	Excavation or surface find
GCP-1	Clovis projectile point	AM281	Excavation
GCP-2	Clovis projectile point	NH1001	Excavation
GCP-3	Clovis projectile point	UT4470-9	Excavation
GCP-5	Clovis projectile point	UT2408-8	Excavation
GCP-6	Clovis projectile point	UT3227	Surface find
GCP-7	Clovis projectile point	UT2938-5	Surface find
GCP-8	Clovis projectile point	UT4651	Surface find
GCP-9	Clovis projectile point	AM383-24	Excavation
GCP-10	Clovis projectile point	UT3251	Excavation
GCP-11	Clovis projectile point	UT4805-5	Surface find
GCP-12	Clovis projectile point	UT1040-113	Surface find
GCP-13	Clovis projectile point	UT2624	Surface find
GCP-14	Clovis projectile point	UT2737	Surface find
GCP-15	Clovis projectile point	UT36-42	Surface find
GCP-16	Clovis projectile point	UT3103	Surface find
GCP-17	Clovis projectile point	UT2621	Surface find
GCP-18	Clovis projectile point	AM228	Excavation
GCP-19	Clovis projectile point	UT3057	Excavation
GCP-20	Clovis projectile point	UT2396-2	Excavation
GCP-21	Clovis projectile point	UT1007	Surface find
GCP-22	Clovis projectile point	UT2748	Excavation
GCP-23	Clovis projectile point	UT1148-2-3	Excavation
GCP-24	Clovis projectile point	AM277-2	Excavation
GCP-25	Clovis projectile point	UT4543	Excavation
GCP-26	Clovis projectile point	PC2234-17	Excavation
GCP-27	Clovis projectile point	BB2115-11	Excavation
GCP-28	Clovis projectile point	AM191-174	Excavation
GCP-29	Clovis projectile point	UT2643-15	Excavation
GCP-30	Clovis projectile point	UT3559	Surface find
GCP-31	Clovis projectile point	UT2037	Surface find
GCP-32	Clovis projectile point	UT1286-5	Surface find
GCP-33	Clovis projectile point	NH1323	Excavation
GCP-34	Clovis projectile point	UT3017	Excavation
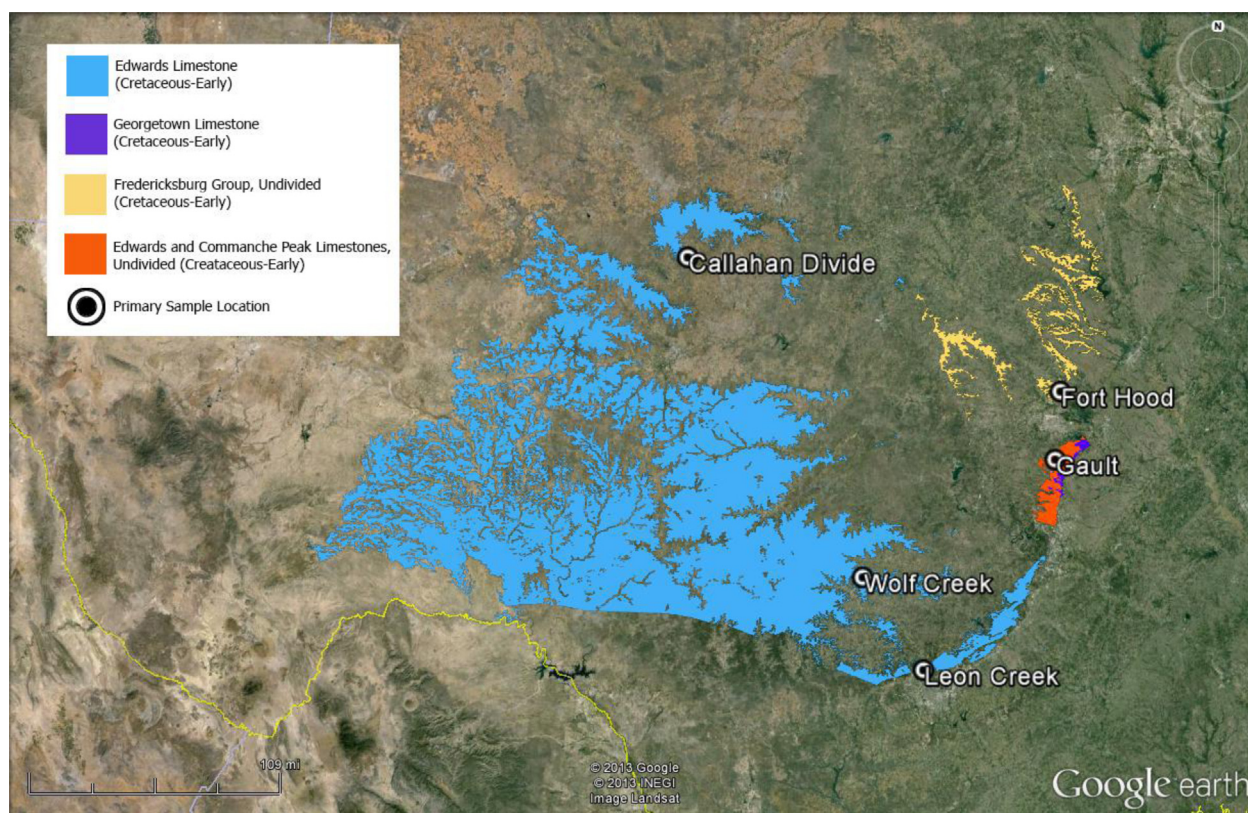
Fig. 1. Edwards Plateau study area and associated features.

Flint was selected for geochemical testing in order to provide a contrasting source from well beyond the Edwards Plateau region. Additionally, several Edwards Plateau chert sources are macroscopically similar to Knife River Flint. It has been suggested in the archaeological literature that Clovis artifacts were frequently made from Knife River Flint and were transported great distances (Stright et al., 1999; Ahler, 1983; Hoard et al., 1993; Tankersley, 1991). Additionally, it has been suggested that Paleoindian artifacts from the McFaddin Beach site along the Texas Gulf Coast were made of Knife River Flint (Banks, 1999).

The Gault Clovis projectile points' geochemistry will be compared to those of the geologic samples at three different spatial scales. The first is the macro-regional scale, which focuses on comparison of the Edwards Plateau chert geologic samples with those of Knife River Flint from North Dakota. The second is at the regional scale, which focuses on comparison of four different areas of the Edwards Plateau including: the Callahan Divide, the Gault/Fort Hood, Leon Creek, and Wolf Creek. Lastly, the local scale which focuses on comparison of five areas within the Gault/Fort Hood area. These five areas include the Gault Site Source Area, Gault Source 1, Gault Source 2, Adventure Ranch, and Fort Hood.

2.1. Edwards Plateau chert

The Edwards Plateau marks the southern edge of the Great Plains and is a significant part of the Southern High Plains. Several important Clovis period sites have been discovered near and on the Edwards Plateau. The lithic assemblages from some of these sites are thought to possess Edwards Plateau chert, including the Clovis type site Blackwater Draw (Boldurian and Cotter, 1999), the Aubrey Site (Ferring, 2001), Pavo Real (Collins et al., 2003), and the Gault Site (Collins, 2007). The Edwards Plateau region and associated limestone formations occur over an area nearly a fifth the size of Texas (120,000 km^2). The Edwards Plateau is considered one of the largest chert bearing formations in North America (Banks, 1990). The Edwards Plateau cherts that were tested for this project were all derived from Lower (Early) Cretaceous limestone deposits of the Edwards Plateau region in central, south-central, and north-central Texas (see Fig. 1). Edwards Plateau region cherts are often described as gray, cryptocrystalline siliceous rocks (Banks, 1990; Frederick and Ringstaff, 1994). Many areas of the Edwards Plateau do contain large quantities of gray cherts. However, defining precisely what Edwards Plateau region cherts are is quite difficult. This is due to a tremendous amount of macroscopic variation in color, texture, and form for many cherts that occur on the Edwards Plateau (Boldurian and Cotter, 1999; Amick, 1996; Boldurian, 1991; Tunnell, 1978). As an example, the Killeen-Fort Hood area of Texas possesses chert with a tremendous amount of color, texture, and form variation (Frederick and Ringstaff, 1994) with 28 different macroscopic varieties of chert occurring locally that have been documented (Abbott and Trierweiler, 1995).

There may be some geochemical correlation among chert sources within a single geological formation but this cannot be assumed and must be evaluated with geochemistry. It was found in Speer (2014) using LA-ICP-MS that Edwards Plateau cherts were more similar to each other than they were to another major source of siliceous rock, Knife River Flint. It was also shown at the regional and local scale, chert sources possessed enough similarity in their trace element geochemistry to create distinguished groups. For a complete discussion of the Edwards Plateau cherts and their formation processes please see Speer (2014).

2.2. Knife River Flint

Knife River Flint is hypothesized to exist primarily as secondary sources derived from the Killdeer Mountains (Murphy, 2001) but the primary source has not yet been located. It is suggested that North Dakota Knife River flint primarily derives from either the Golden Valley or White River Formations. Therefore, only secondary sources were used in this study and those are from McLean County in central North Dakota along the Knife River. The geology of McLean County and North Dakota can be found in detail elsewhere (Murphy, 2001; Bluemle, 1980, 1988; Benson, 1953) as well as archaeological sourcing projects dealing with White River Group and Sentinel Butte formations (Hoard et al., 1993, Huckell et al., 2011).

2.3. The Gault Site

The Gault Site is located between several ecological zones bracketing the Balcones Escarpment including, importantly, the Edwards Plateau and the Post-Oak Savannah (Hester, 1998; Collins, 2002). The Gault Site is near a year-round spring feature, Buttermilk Creek, which is active even during severe drought conditions. The Gault Site is also adjacent to a high quality source of Edwards Plateau chert. First excavated by J.E. Pearce in 1929–1930, Gault was subject to extensive looting, especially in the 1980s and 1990s. Looting primarily damaged the upper Archaic deposits but did not reach Paleoindian levels. The Gault Site is large, covering approximately 16 ha. The Clovis deposits at Gault are estimated to cover 3 ha. Excavations at Gault, under the direction of Michael Collins since 1998, have only uncovered an estimated 2–3 percent of these Clovis deposits (Collins 2010, personal communication). The Gault Site has produced compelling evidence for an Older Than Clovis (OTC) occupation (Collins and Bradley, 2008) and is several hundred meters from the Debra L. Friedkin Site, also with OTC deposits (Waters et al., 2011a). The Gault Site to date has produced an extensive collection of Clovis stone tools and manufacturing debris of approximately 600,000 artifacts. This represents nearly 55 percent of all Clovis period provenienced artifacts ever excavated (Collins, 2007, 2013).

The Gault Site is one of the few Clovis period sites that is not solely a megafauna kill/butchering site (Cannon and Meltzer, 2004). Although remains of megafauna have been discovered at the site, the dominant activity appears to be that of a quarry/campsite (Collins, 2007; Smallwood, 2007; Shoberg, 2010). Additionally, the Gault Site joins a list of other sites that have diverse faunal remains such as Aubrey, Blackwater Draw, Horn Shelter 2, Kincaid, Lewisville, and Lubbock Lake (Boldurian and Cotter, 1999; Collins, 2007, 2002; Rhode and Louderback, 2007; Bousman et al., 2004, Bousman et al., 2002; Witt, 2005; Perttula, 2004; Bousman and Oksanen, 2012). There are growing bodies of evidence suggesting Clovis period hunter–gatherers were not highly mobile big game specialists, but rather subsistence generalists with occasional hunting forays (Pinson, 2011; Haynes and Huckell, 2007; Walker and Driskell, 2007; Graf and Schmitt, 2007; Smith, 2007; Jones et al., 2003). Future publications derived from the results presented here will be treated fully in regards to these topics; especially in regards to hunter gatherer mobility, raw material procurement, use-life, resharpening, and discard patterns of Clovis period projectile points.

3. Materials and methods

3.1. Materials

The macroscopic homogeneity of Edwards Plateau chert (Banks, 1990) is problematic because chert may have been moved by humans several hundred kilometers in prehistory from one edge of the Edwards Plateau to another; or from the Edwards Plateau to another geographic location, as seen in some Folsom assemblages

(Hofman et al., 1991; Clark and Collins, 2002). In order to understand Clovis mobility in this context, it is vital that the Edwards Plateau chert identified in the Gault assemblages are attributed to a specific geologic formation and not to the massive area defined as the Edwards Plateau (see Fig. 1). All of the chert Clovis projectile points (33 in total) that have been recovered from the Gault Site were selected for LA-ICP-MS analysis. Approximately 26 of the 33 Gault Clovis period chert projectile points appear visually to be made from chert which is macroscopically similar to chert sources within 30 km of the Gault Site. The projectile points recovered from the Gault site are from multiple series of excavations and surface finds dating back more than 20 years (Collins, 2002; Bradley et al., 2010; Waters et al., 2011b). There is potential that these projectile points are not made from these local sources but from chert sources elsewhere on the Edwards Plateau. One option to evaluate whether the Gault Clovis projectile points are made from any of these sources is through geochemical analysis.

3.2. Methods

In order to accurately determine from where an artifact is derived the same techniques that are applied to understanding reference geologic chert samples in a database must also be applied to artifacts. The protocols listed below for the Clovis period projectile points are the same as those used for the 242 reference geologic samples that were tested in Speer (2014). Canonical discriminant analysis and linear discriminant analysis identified groups using trace element data and all geologic samples were correctly classified. Each artifact was tested at three spatial scales. These include the macro-regional (greater than 500 km between sources), regional (30–500 km between sources), and local (less than 1–30 km between sources). These terms and distances are arbitrary and are based on the maximum distance between the sources analyzed.

The Clovis period projectile points were analyzed at the Field Museum of Natural History using LA-ICP-MS with the procedures listed below. Canonical discriminant analysis was used to create geochemical profiles for each of the artifacts with which to compare to geochemical groups. Geochemical groups established from the geologic reference samples.

Analysis consisted of directing the beam of a laser at 10 separate locations (single point) on each artifact sample. Artifacts tested with the laser ablation units are listed in Table 1. In order to determine elements with concentrations in the range of parts-per-million (ppm) and below, a single point analysis mode with a laser beam diameter of 100 microns, operated at 70 percent of the laser energy (0.2 mJ) and a pulse frequency of 15 Hz was employed. A pre-ablation time of 20 s was set up in order to eliminate the transient part of the signal and to be sure that possible surface contamination or corrosion did not affect the results of the analysis (Dussubieux et al., 2009; Speakman and Neff, 2005b). The laser vaporizes a volume of material corresponding to a cylinder with a diameter of 100 microns.

Following ablation the ablated material from the sample was transported by helium/argon carrier gas to the ICP-MS (Varian 810 quadrupole ICP-MS unit). At the plasma torch section of the ICP-MS the sample encountered argon plasma between 8000 K and 10,000 K and was ionized. There the ion beam was bent through a 90° reflecting ion optics system. "The 90° reflecting ion mirror achieves a transmission efficiency gain of as much as 200 times compared with the theoretical calculations for conventional linear ICP-MS systems. This translates into sensitivity that can be adjusted on the fly from low megahertz (millions of cps/mg/L) to gigahertz (1000 Mcps/mg/L)" (Elliot et al., 2004). For most elements, the instrument can measure accurately to the sub-parts per million

(ppm) level (Kellet et al., 2013). The ionized samples were then introduced into the mass spectrometer section of the instrument where the ions were characterized by their mass/charge ratios to determine which element they represented and their overall relative quantity (Trejos et al., 2003).

Each of the 10 single point locations were analyzed for 58 elements and 9 individual readings with the first 3 readings always discarded to avoid potential surface contamination. The remaining six samplings were then averaged for each sample. Each sample was therefore represented by the composition of 58 elements and an average concentration in parts per million calculated from 60 measurements (10 single points with 6 readings per point). For each chert sample, measurements are corrected from the blank used in the calculation of concentrations. The blank is a reading taken with no material ablated or introduced into the ICP-MS. Silica is the most abundant component in chert, therefore, the ^{29}Si isotope was used for internal standardization (Gratuze, 1999, 2001). Concentrations for major components, including silica, were calculated assuming that the sum of their concentrations in percent of oxide in chert is equal to 100 percent (adapted from Gratuze, 1999). Two different series of standard reference materials were used to determine the concentrations of major, minor and trace elements. The first series of external standards were NIST SRM 610 and 612. Both of these standards are soda-lime-silica glass doped with trace elements in the range of 500 ppm (SRM 610) and 50 ppm (SRM 612). Certified values are available for a very limited number of elements; concentrations from Pearce et al. (1997) were used for the other elements.

The second series of standards used were Corning Glasses B and D (Brill, 1999). Of the 58 elements that were tested for all samples, 44 were found to be trace elements (see Table 2). A trace element is defined as any chemical element in a rock's composition that has a concentration of less than 1000 ppm, or less than 0.1 percent by weight (White, 2013). The trace elements were used to determine geochemical groups as they are the best indicator of formation geochemistry (White, 2013). Prior to analysis, it was necessary to convert all concentration data using a base-10 logarithm of each concentration to remove magnitude in differences and provide normal distribution.

4. Statistical analysis

Canonical discriminant analysis was used here to produce graphical results. Linear discriminant analysis was used to determine if an artifact was statistically similar to the geologic group it was assigned to with canonical discriminant analysis. All artifacts were analyzed in this way. In cases where overlap of two or more geologic groups occurred, linear discriminant analysis was used to find the group the artifact was most similar to statistically.

Based on Weigand et al. (1977) provenance hypothesis, different chemical groups are assumed to characterize geographically constrained sources. Toolstones such as cryptocrystalline silicates (e.g., chert, flint, or jasper) and obsidian are collected from known outcrops and the compositional data derived from geologic samples defines source localities or boundaries (Glascock et al., 1998; Quigg et al., 2008).

The most important variable that must be attached to every geologic sample used for comparison with artifacts is its geographic coordinates; which allows assignment of a class variable for its source. By incorporating the provenience of the geologic samples, linear discriminant analysis (Johnson and Wichern, 2007) can be used. It has been used with great effectiveness in multiple industries including: petroleum (Gerrild and Lantz, 1969), wine (Loredana La Torre et al., 2008), and palm print recognition software (Xiangua et al., 2003). For example, the chemical signatures of

Table 2
The 44 trace elements used in the statistical analysis.

Element name	Symbol (atomic number)	Element category
Lithium	Li (3)	Alkali metal
Beryllium	Be (4)	Alkaline earth metal
Boron	B (5)	Metalloid
Scandium	Sc (21)	Transition metal
Titanium	Ti (22)	Transition metal
Vanadium	V (23)	Transition metal
Chromium	Cr (24)	Transition metal
Nickel	Ni (28)	Transition metal
Cobalt	Co (27)	Transition metal
Zinc	Zn (30)	Transition metal
Rubidium	Rb (37)	Alkali metal
Strontium	Sr (38)	Alkaline earth metal
Zirconium	Zr (40)	Transition metal
Niobium	Nb (41)	Transition metal
Silver	Ag (47)	Transition metal
Indium	In (49)	Post-transition metal
Tin	Sn (50)	Post-transition metal
Antimony	Sb (51)	Metalloid
Cesium	Cs (55)	Alkali metal
Barium	Ba (56)	Alkaline earth metal
Lanthanum	La (57)	Lanthanide
Cerium	Ce (58)	Lanthanide
Praseodymium	Pr (59)	Lanthanide
Tantalum	Ta (73)	Transition metal
Gold	Au (79)	Transition metal
Yttrium	Y (39)	Transition metal
Lead	Pb (82)	Post-transition metal
Bismuth	Bi (83)	Post-transition metal
Uranium	U (92)	Actinide
Tungsten	W (74)	Transition metal
Molybdenum	Mo (42)	Transition metal
Neodymium	Nd (60)	Lanthanide
Samarium	Sm (62)	Lanthanide
Europium	Eu (63)	Lanthanide
Gadolinium	Gd (64)	Lanthanide
Terbium	Tb (65)	Lanthanide
Dysprosium	Dy (66)	Lanthanide
Holmium	Ho (67)	Lanthanide
Erbium	Er (68)	Lanthanide
Thulium	Tm (69)	Lanthanide
Ytterbium	Yb (70)	Lanthanide
Lutetium	Lu (71)	Lanthanide
Hafnium	Hf (72)	Transition metal
Thorium	Th (90)	Actinide

wines are tied to their geographic origin to form unique composition groups. If a geologic sample cannot be accurately assigned to a geographical location and it is included in the study, the technique will fail because the geochemical group being created by the trace elements from unknown samples would add information that alters the group profile to an extent that it may include either geologic samples not from the formation or identify artifacts as being related to that geochemical group when they are not.

The process of data analysis of archaeological materials using canonical discriminant analysis and linear discriminant analysis is found in significant detail in other sources (Glascock et al., 1998; Baxter, 1994; Bishop and Neff, 1989; Baxter and Buck, 2000). These two types of analysis were used for rigorous confirmation of patterns as seen in other, similar studies (Huckell et al., 2011).

A significant problem that arises in statistical analysis is the incorporation of data which has zero values for certain variables (in this case geochemical elements). The options are either to include the sample with the zero value, eliminate the variable for all samples, include the variable and eliminate the sample, or replace the zero value with the mean for that variable. The elimination of a sample because of a single missing value is not acceptable. This is because the element may be present but not detectable with the current technology employed. The replacement of missing values with the mean for an element is also not acceptable when

developing a geochemical reference database. This is because this is the stage at which *all* variability across the formation is being documented. Therefore, if any sample had a zero value it was left in place for the entire sample set. A zero value was assigned following base-10 logarithmic transformation as the log10 of a zero value is undefined.

The one exception to this was the values for the element arsenic (Ar) which were excluded for all samples due to it not being detected for over 50 percent of all geologic samples. There were no clear patterns for the lack of arsenic concentrations in any of the sample sets whether macro-regionally, regionally, or locally. This procedure worked well for all cases and did not necessitate estimations of geologic formation geochemistry. As mentioned before, 44 elements were found to be trace elements (see Table 2). The statistical analyses focused on the 44 trace elements as trace elements have the greatest potential for identifying geologic sources (White, 2013).

The concentration data from the 44 trace elements retrieved was analyzed using multivariate quantitative analysis in JMP Pro 10 Statistical Discovery by SAS. The primary goal of multivariate analysis is to determine if there exist homogeneous groups within the geochemical database. First, the data was assessed using canonical discriminant analysis to produce graphical results based on 95 percent probability ellipses (Khattree and Naik, 2008). Linear discriminant analysis was then used for verification of geochemical patterns using a predictive probability for group inclusion for all cases to verify they were correctly assigned using canonical discriminant analysis. Also, linear discriminant analysis was used in cases where artifacts fell in between two or more overlapping 95 percent confidence ellipses for geochemical groups in the canonical discriminant analysis (Johnson and Wichern, 2007). This yielded probability values for membership in both overlapping groups. The larger value clearly allowed discrimination between the alternative group membership. This gives the best approximation to which group the sample is most similar to. Therefore, linear discriminant analysis is used to determine which group is the better statistical fit for that particular simulated artifact. At each of the three declining spatial scales a new round of statistical analyses was implemented. If any artifact did not fall within a 95 percent confidence interval for the canonical discriminant analysis it was considered an unknown and eliminated from the next scale analysis.

5. Results and discussion

The results are presented here at each of the three spatial scales. All of the artifacts are presented in the canonical discriminant graphs below and are paired with tables of probability of group membership for reference generated by linear discriminant analysis. The geologic group determined for each artifact and the probability of group membership is listed in parentheses for that group in Table 3. At the macro-regional scale 21 of the 33 projectile points were attributed to the Edwards Plateau group and none of the projectile points fell into an overlapping area at the macro-regional scale. At the regional scale 15 of the projectile points were attributed to a particular region. Of these five fell within overlapping areas, four of which were resolved to a single region through linear discriminant analysis, and one sample (GCP-23) remained ambiguous. At the local scale, two of the projectile points were attributed to a particular local area and both fell within overlapping areas.

5.1. Macro-regional

At the macro-regional scale 21 of the 33 (64 percent) of the Gault Clovis period projectile points had similar trace element

Table 3
Group geochemistry assignments for Gault Clovis projectile points. Probability values are from linear discriminant analysis.

Sample	Macro-regional group (probability)	Regional group (probability)	Local group (probability)
GCP-1	Edwards Plateau (100%)	x	x
GCP-2	Edwards Plateau (100%)	Callahan Divide (74.919%)	x
GCP-3	Edwards Plateau (100%)	Callahan Divide (65.913%)	x
GCP-5	Edwards Plateau (100%)	Gault & Fort Hood (99.779%)	Gault Source 2 (87.847%)*
GCP-6	Edwards Plateau (100%)	Leon Creek (98.160%)	–
GCP-7	Edwards Plateau (100%)	Leon Creek (60.667%)*	x
GCP-8	Edwards Plateau (100%)	Leon Creek (99.999%)	–
GCP-9	x	x	x
GCP-10	Edwards Plateau (100%)	x	x
GCP-11	x	x	x
GCP-12	Edwards Plateau (100%)	Gault & Fort Hood (99.459%)	Gault Source 1 (99.998%)*
GCP-13	Edwards Plateau (100%)	Callahan Divide (88.043%)*	x
GCP-14	Edwards Plateau (100%)	x	x
GCP-15	Edwards Plateau (100%)	Gault & Fort Hood (81.593%)*	x
GCP-16	Edwards Plateau (100%)	Gault & Fort Hood (83.242%)	x
GCP-17	Edwards Plateau (100%)	x	x
GCP-18	Edwards Plateau (100%)	Gault & Fort Hood (98.984%)	x
GCP-19	Edwards Plateau (100%)	Gault & Fort Hood (96.539%)*	x
GCP-20	Edwards Plateau (100%)	Gault & Fort Hood (97.480%)	x
GCP-21	Edwards Plateau (100%)	Gault & Fort Hood (98.863%)	x
GCP-22	Edwards Plateau (100%)	Gault & Fort Hood (97.956%)	x
GCP-23	Edwards Plateau (100%)	Callahan Divide (93.681% LDA match for Gault/Fort Hood)**	x
GCP-24	Edwards Plateau (100%)	x	x
GCP-25	x	x	x
GCP-26	x	x	x
GCP-27	x	x	x
GCP-28	x	x	x
GCP-29	x	x	x
GCP-30	x	x	x
GCP-31	x	x	x
GCP-32	x	x	x
GCP-33	x	x	x
GCP-34	x	x	x

"x" = not within any 95% confidence interval ellipse.
"*" = classified in overlapping area of two or more 95% confidence interval ellipses.
"**" = sample results ambiguous.
"–" = not enough geologic samples to test at this scale.
Macro-Regional Groups: Edwards Plateau, Knife River.
Regional Groups: Gault & Fort Hood, Leon Creek, Callahan Divide, Wolf Creek.
Local Groups: Gault Site Area, Gault Source 1 & 2, Adventure Ranch, Fort Hood.
GCP-4 was determined to not be a projectile point but a preform.

geochemistry to geologic samples from the Edwards Plateau using the current database. As more of the variability of Edwards Plateau chert is documented, more of these projectile points may fall within the 95 percent confidence ellipse. For the macro-regional scale, 12 Clovis projectile points were outside of the Edwards Plateau 95 percent confidence ellipse (see Table 3). None of the Clovis projectile points fell within the Knife River Flint 95 percent confidence ellipse. Of the projectile points tested 64 percent were within the 95 percent confidence interval and were statistically more similar to the Edwards Plateau group according to linear discriminant analysis for advancing to the regional scale (see Fig. 2).

5.2. Regional

At the regional level, 15 of the 33 (45 percent) Gault Clovis projectile points tested could be identified to a particular region within the Edwards Plateau. For the Callahan Divide region, three Clovis projectile points had similar geochemistry. These included GCP-2, GCP-3, and GCP-13. Clovis projectile points GCP-2 and GCP-3, match very well within the Callahan Divide 95 percent confidence ellipse and are more like the Callahan Divide geologic samples than geologic samples from other regions. The linear discriminant analysis probabilities were 75 percent for GCP-2 and 66 percent for GCP-3 (see Table 3 and Fig. 3). GCP-13 was within the

95 percent confidence interval for the Callahan Divide but fell into an overlapping area with the Gault/Fort Hood area. Linear discriminant analysis showed that GCP-13 was 88 percent more similar to the geologic samples from the Callahan Divide.

For the Leon Creek region, three of the Gault Clovis projectile points were similar to this area's geologic samples. These included GCP-6, GCP-7, and GCP-8. Gault Clovis projectile points GCP-6 and GCP-8 were likely from Leon Creek geologic material as they fell within the 95 percent confidence interval in non-overlapping areas. Additionally, GCP-6 and GCP-8 were similar to the Leon Creek geologic samples using linear discriminant analysis at 98 percent and 100 percent probabilities respectively. The geologic group assignment of Clovis projectile point GCP-7 is difficult at this time because it fell into an area overlapped by the Gault/Fort Hood, Callahan Divide, and Leon Creek confidence ellipses. Using linear discriminant analysis suggests that GCP-7 is most like the Leon Creek region cherts. It was more similar to the Leon Creek geologic samples than the other regional samples with a relatively low linear discriminant analysis probability of 61 percent for Leon Creek. This suggests that the testing of more geologic samples from Leon Creek may fully document the geochemical variability for this area and help determine if GCP-7 is indeed derived from the Leon Creek area.

At the regional scale, 9 of the Gault Clovis period projectile points had highly similar trace element geochemistry to geologic
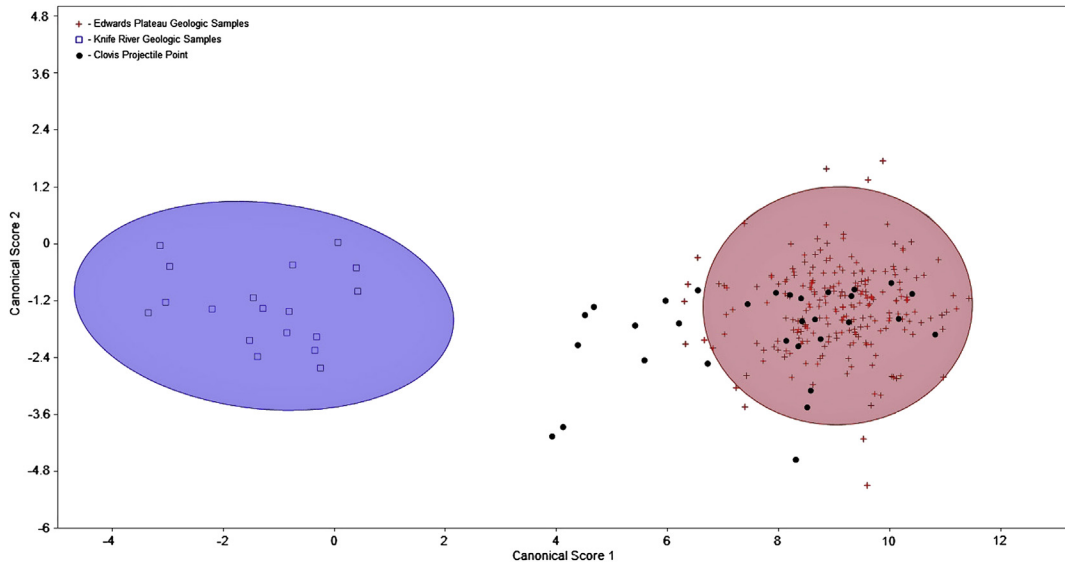
Fig. 2. Canonical discriminant analysis results of Gault Clovis projectile points at macro-regional scale. Ellipses represent 95% confidence interval.

samples from the Gault/Fort Hood area. These included GCP-5, GCP-12, GCP-15, GCP-16, GCP-18, GCP-19, GCP-20, GCP-21, and GCP-22. Projectile points GCP-15 and GCP-19 fell within the overlapping area of the 95 percent confidence ellipses of both Gault/Fort Hood and Leon Creek. However, the linear discriminant analysis probabilities of 82 percent for GCP-15 and 97 percent for GCP-19 both suggest geochemical similarity to Gault/Fort Hood geologic samples.

GCP-23 was an anomaly that cannot be adequately explained at this time. GCP-23 falls in the middle of the Callahan Divide 95 percent confidence ellipse but linear discriminant analysis shows that this sample is very different from the Callahan Divide with 94 percent similarity to the Gault/Fort Hood area. This may represent the fact that the complete geochemical variability for the Gault/Fort Hood region has not yet been determined. Therefore, GCP-23 falls outside of the 95 percent confidence interval of the Gault/Fort Hood group at this time but may be encapsulated as more samples are added to the database. The geochemistry of GCP-23 illustrates the

importance of using linear discriminant analysis probability measure to double check the accuracy of canonical discriminant analysis, particularly in cases where 95 percent confidence ellipses cluster closely and/or overlap.

5.3. Local

The canonical discriminant analysis for the Gault/Fort Hood area revealed that Adventure Ranch, Gault Source 1, and Gault Source 2 were highly similar to each other and had significant overlap of their 95 percent confidence ellipses (see Fig. 4). Only seven projectile points could be tested at the local scale because only the Gault and Fort Hood region had a large enough number of tested unique source areas and geologic samples to perform analysis at this scale. Only GCP-5 and GCP-12 could be accurately assigned to a local scale group. GCP-5 fell within an overlapping area of the Gault Source 1 and Gault Source 2 95 percent confidence ellipses. Linear discriminant analysis suggests that GCP-5 is more geochemically
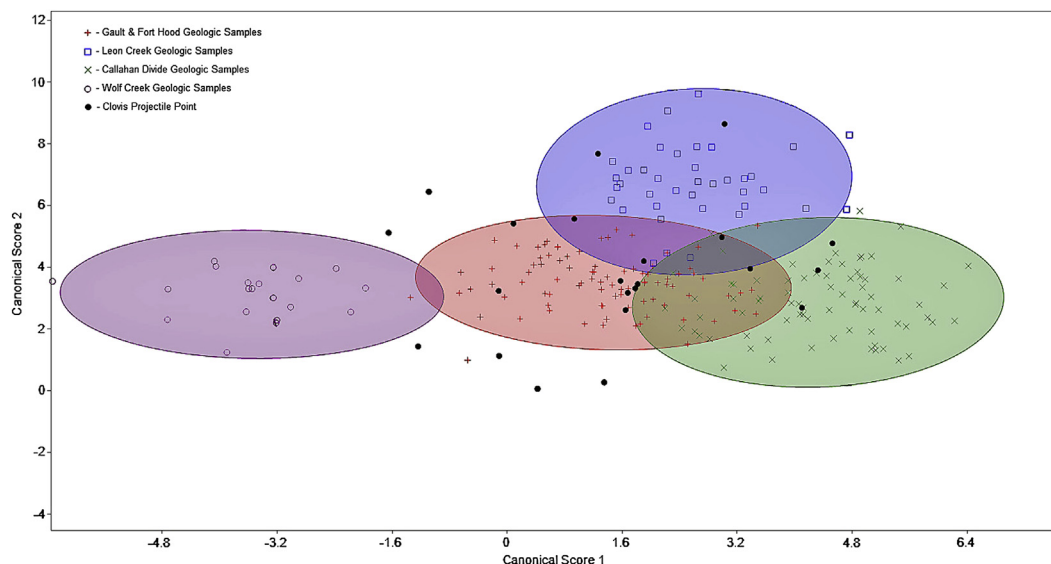

Fig. 3. Canonical discriminant analysis results of Gault Clovis projectile points at regional scale. Ellipses represent 95% confidence interval.
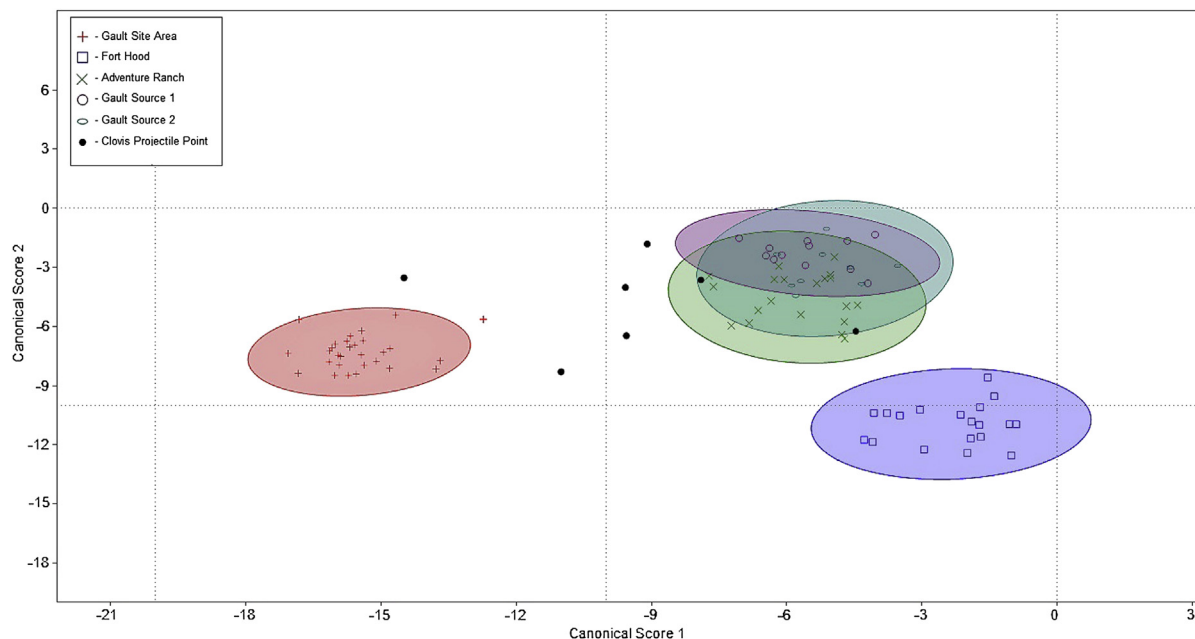
Fig. 4. Canonical discriminant analysis results of Gault Clovis projectile points at local scale. Ellipses represent 95% confidence interval.

similar to Gault Source 2 with 88 percent probability. GCP-12 also fell within an overlapping area of Gault Source 1 and Gault Source 2. Linear discriminant analysis suggests that GCP-12 is more geochemically similar to Gault Source 1 with 100 percent probability.

It may be that future testing can determine if the Adventure Ranch, Gault Source 1, and Gault Source 2 groups can be combined into a homogenous, local group or not. Clovis projectile points GCP-18, GCP-19, GCP-20, GCP-21, and GCP-22 did not fall within the 95 percent confidence ellipse of any local group. The testing of more local scale sources may capture the variability of these Clovis projectile points that do not match any of the currently tested areas. Therefore, at this time only projectile point GCP-5 and GCP-12 can be identified to the local scale.

This provides a demonstration of the effectiveness of the methodology and statistical treatment. It is shown that the closer sources are the more difficult it becomes to discriminate among them. These sources are within 1—30 km of each other. However, when the outcrops are from different formations, as may be the case with the Gault Site Area source versus Gault Source 1, Gault Source 2, and Adventure Ranch, there is clear differentiation. However, the use of linear discriminant analysis allows the effective discrimination of sources and artifacts at the local scale for sources that are highly similar such as Gault Source 1, Gault Source 2, and Adventure Ranch.

5.4. Brief anthropological implications

As mentioned above, a complete anthropological discussion of the implications will appear in future publications but it is worth noting here several important discussion topics. The ability to distinguish a large percentage (64 percent) of the Clovis period projectile points as being manufactured from Edwards Plateau chert at the macro-regional scale is important because it emphasizes intensive exploitation of the region with significant mobility. However, at the regional scale it becomes clear that sources outside of the local area were also being utilized, further strengthening the argument that the Edwards Plateau chert resources were used intensively and widely spread across the region. However, at the

regional scale it is difficult to make interpretations about mobility practices because of the lack of fine-grained chronometric data at the Gault site as well as some of the projectile points being surface finds. It is difficult at this time to determine if these resources were exploited directly or indirectly through social interaction (Meltzer, 1989, 2004; Rissetto, 2009). However, when other data from the projectile points is analyzed in tandem with the geochemistry, such as metric, degree of resharpening, discard patterns, etc., interesting patterns begin to emerge that are too lengthy to treat fully here.

6. Conclusions

This study illustrates that using LA-ICP-MS techniques and multivariate statistics can advance understanding of the concept of local versus non-local toolstone resources for Clovis period foragers. The ability to determine whether artifacts were made from sources at the macro-regional, regional, and local scale is shown. In broad terms, this study found three conclusions: artifacts can be tested at several scales of resolution; criteria can be applied to the geochemistry of an artifact to determine if it can be further tested with the geologic geochemical data available; and determine how similar each artifact is to a particular geologic source area. The methodological approach presented is effective at sourcing chert at multiple scales. The data appears to suggest that the chert Clovis projectile points from the Gault Site are manufactured from sources across the Edwards Plateau.

This study analyzed the trace element geochemistry of 33 Clovis projectile points from the Gault Site and used canonical discriminant analysis and linear discriminant analysis to determine if any of the Clovis projectile points were statistically similar to several chert source areas within the Edwards Plateau. This study revealed that at a macro-regional scale, 21 of the 33 (~64 percent) Clovis projectile points were geochemically similar to currently tested chert sources within the Edwards Plateau. At the regional scale, 15 of the 21 Clovis projectile points (~45 percent) were more precisely defined to three regions of the Edwards Plateau; three (~10 percent) from the Callahan Divide region, three (~10 percent) from the Leon Creek region, and nine (~21 percent) from the Gault/Fort Hood region. Lastly, this study showed that only two (~6 percent) of

the 15 regionally identified points could be given more precise attribution at the local scale; with one deriving from Gault Source 1 and the other deriving from Gault Source 2.

This study is effective at sourcing some of the Clovis projectile points from the Gault site because of the integration of particular characteristics of the methodology. The first is that this study focuses only on primary sources for the Edwards Plateau geologic samples that can reliably be traced back to a fixed geographic location. The second is that this study incorporates a large number of geologic samples (242) with which to test the Gault Clovis projectile points against. The third is the use of LA-ICP-MS and its ability to capture many trace elements when compared to other instrumental techniques. The fourth is the use of the multi-scalar technique. Lastly, this study implements the use of canonical and linear discriminant analysis to maximize the use of geologic samples to determine smaller scales of resolution.

It will take continued building of geochemical databases with large numbers of geologic samples to further refine the spatial scalar model shown here, as well as potentially enhance the ability to determine with increasing accuracy the geologic provenience of artifacts. Ultimately, this information can help determine which types of mobility were practiced by Clovis hunter–gatherers when situated near high quality chert resources. The methodology presented here can help create new approaches to provenance issues and a reconsideration of current methods for others.

Acknowledgments

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.08.014.

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